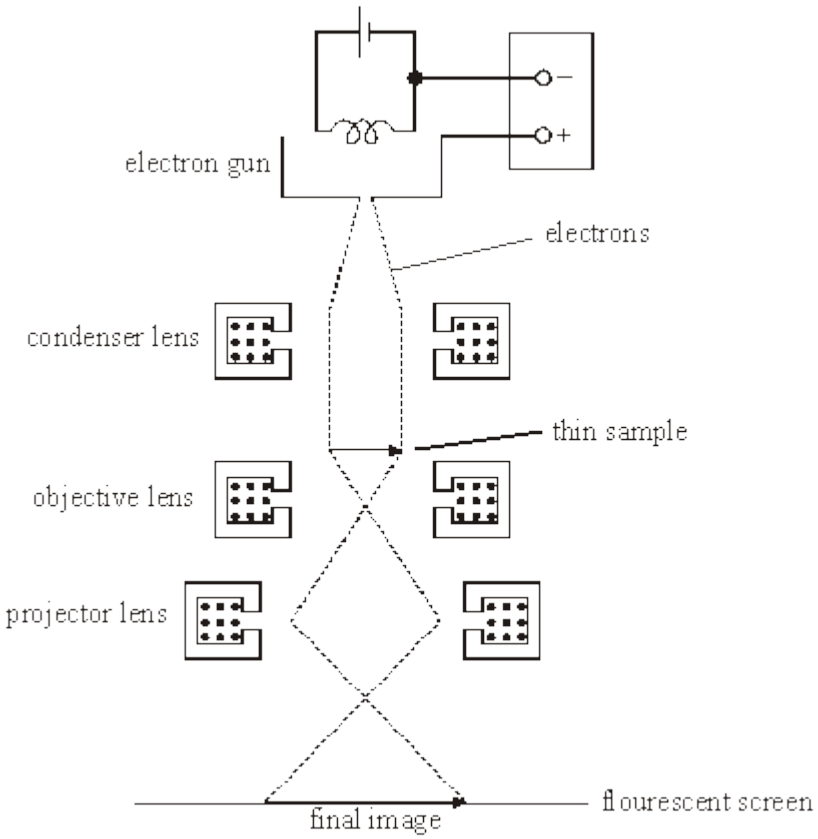
1 In a transmission electron microscope, electrons from a heated filament are accelerated through a certain potential difference and then directed in a beam through a thin sample. The electrons scattered by the sample are focused by magnetic lenses onto a fluorescent screen where an image of the sample is formed, as shown in the figure below.



(a) State and explain **one** reason why it is important that the electrons in the beam have the same speed.

.....

.....

.....

.....

(2)

(b) When the potential difference is increased, a more detailed image is seen. Explain why this change happens.

.....

.....

.....

.....

.....

.....

(3)
(Total 5 marks)

2 The Boolean equation for a particular logic circuit with inputs A and B and output Q is:

$$Q = (A.B) + (\overline{A}.\overline{B})$$

(a) The table below shows intermediate logic signals for the circuit, and the overall output, Q, for all combinations of the inputs A and B.

Complete the missing two entries in the truth table.

A	B	$\overline{A}$	$\overline{B}$	A . B	$\overline{A}$. $\overline{B}$	Q
0	0	1	1	0	1	
0	1	1	0	0	0	0
1	0	0	1	0		0
1	1	0	0	1	0	1

(1)

(b) Complete the diagram in the figure below to show the logic circuit that has the same function as the Boolean equation given above. Your circuit should contain only **two** AND gates, **two** NOT gates, and **one** OR gate.

A

B

Q

(3)
(Total 4 marks)

3 A student designs an electronic system to control a ventilation fan for a greenhouse. The fan should be switched on only when both the temperature and humidity exceed certain levels that can each be set independently.

(a) Choosing appropriate input, process and output subsystems from the list below, draw a labelled block diagram to show a possible design for the system.

Choose from:

AND gate	**comparator**	**driver**	**humidity sensor**
fan motor	**temperature sensor**	**voltage divider**	

(7)

(b) In which subsystem would:

(i) a MOSFET be used .....

(1)

(ii) an op-amp be used .....

(1)

(iii) a thermistor be used? .....

(1)

(c) The controller circuit operates from a 12 V power supply and draws a current of 25 mA under all conditions.
The fan motor requires a current of 450 mA when switched on and operates from the same 12 V power supply.

Calculate:

(i) the total current drawn by the whole system when the fan motor is switched on

.....

(1)

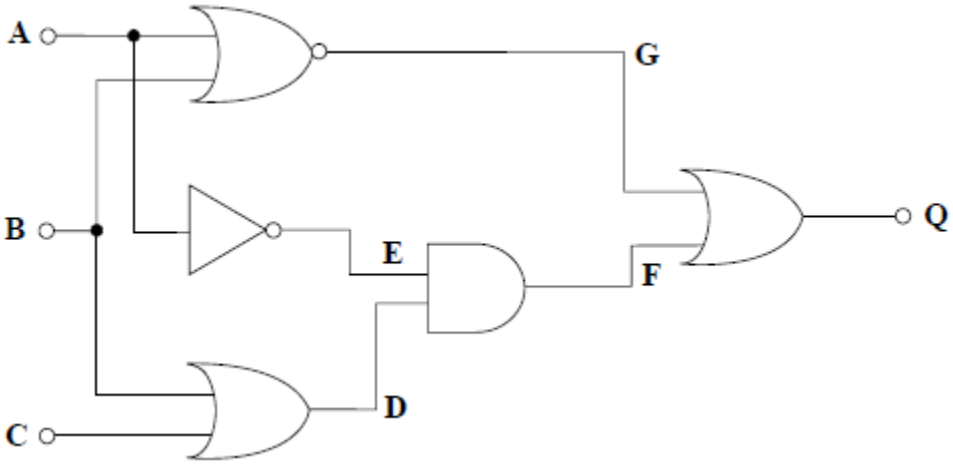
(ii) the input power to the whole system when the fan motor is switched on.

.....

(2)

(Total 13 marks)

4 The diagram shows a logic circuit with three inputs **A**, **B** and **C**.



(a) Write the Boolean expressions for the signals at the intermediate points **D**, **E**, and **G** in terms of the inputs **A**, **B** and **C** only.

D .....

E .....

G .....

(3)

(b) Complete the truth table below for the logic signals at the intermediate points **D**, **E** and **G**.

Inputs			Intermediate points		
C	**B**	**A**	**D**	**E**	**G**
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

(5)
(Total 8 marks)

5 A fridge is fitted with a temperature-sensing unit to indicate whether the temperature inside the fridge is too high, too low, or at a safe temperature.
The system consists of a temperature sensor that produces a 2−bit binary output, a logic circuit and a low current, common cathode 7−segment display.
Figure 1 shows a block diagram of the system.

Figure 1

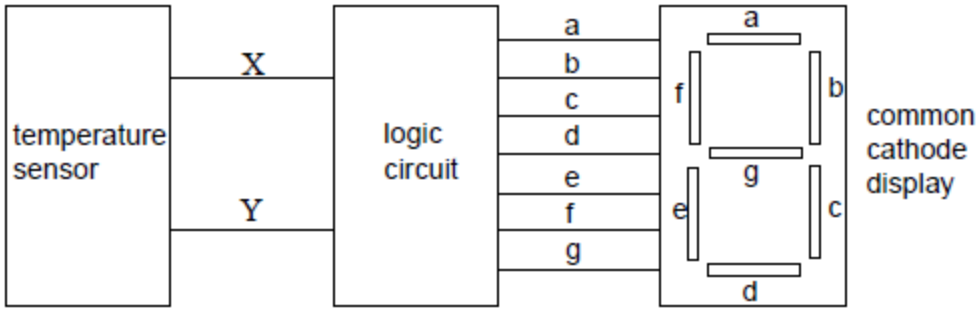


Table 1 shows the operation of the system.

Table 1

Fridge temperature	Temperature sensor output		7-segment display output
	X	Y	
< 3 °C	0	0	L
3 °C to 4 °C	0	1	S
4 °C to 5 °C	1	0	S
> 5 °C	1	1	H

Key
L = low
S = safe
H = high

(a) Complete **Table 2** to show the logic signals required on lines a to g to display the specified characters.

Table 2

X	Y	a	b	c	d	e	f	g	Display
0	0								L
0	1								S
1	0								S
1	1								H

(3)

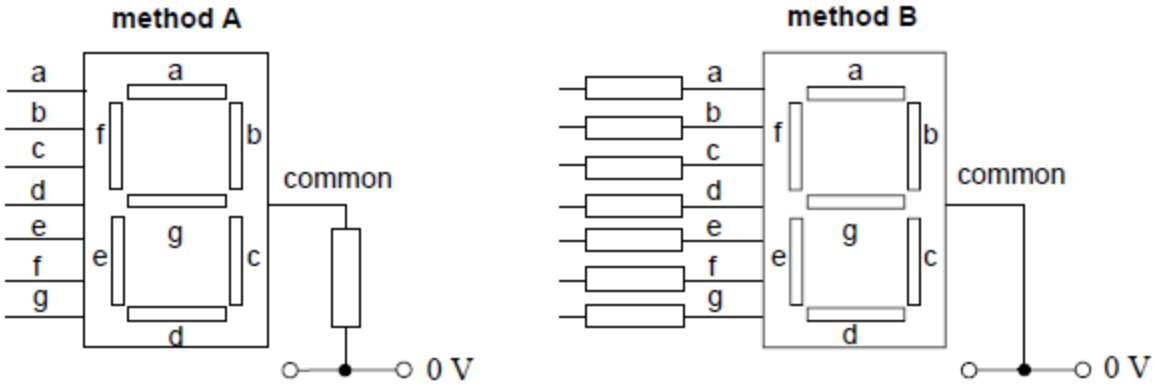
(b) Circle the single logic gate which would generate the required signal for segment **a**.

AND EXOR OR NAND NOR NOT

(1)

(c) The LEDs in the 7−segment display must be protected by current limiting resistors.
Figure 2 shows two methods, **A** and **B**, of connecting current limiting resistors.

Figure 2



(i) State **one** disadvantage of **method A**.

.....

.....

(1)

(ii) Calculate the value of the current limiting resistors required in **method B** to limit the current in each segment to 20 mA.
Assume the voltage from the logic circuit is 5 V and the forward voltage drop across each LED in the 7−segment display is 2.2 V.

.....

.....

.....

(2)

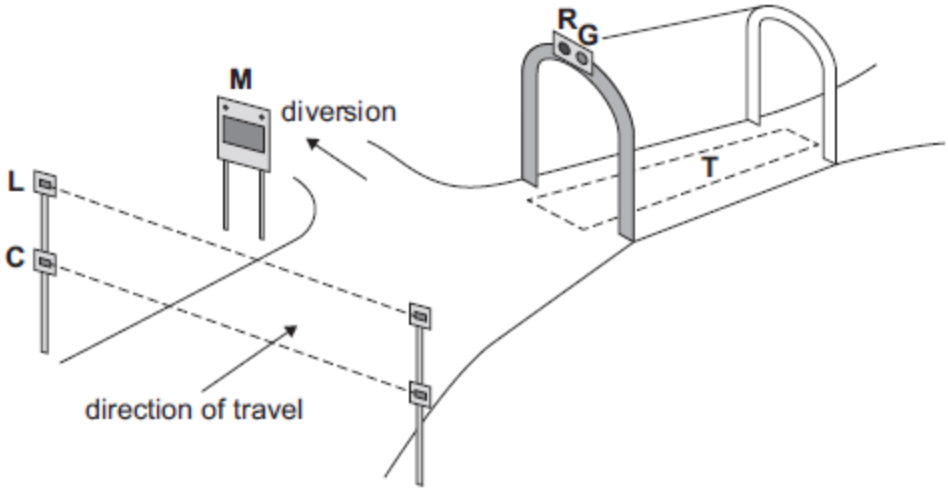
(iii) Circle the appropriate value for these resistors from the following list of E24 resistors.

110 Ω 150 Ω 270 Ω 1.1 kΩ 1.5 kΩ

(1)
(Total 8 marks)

6 Figure 1 shows a simplified diagram of a road safety system for traffic travelling towards a road tunnel. The tunnel is too narrow for two-way traffic and too low for lorries.

Figure 1



C and **L** are laser beam sensors placed at different heights on the road just before the tunnel. When a beam is broken, the sensor produces a logic 1.

Cars will break the beam at sensor **C only**. Lorries will break the beams at both sensor **L** and sensor **C**.

M is an electronic message display that tells lorries to take a diversion. The message display lights up when it receives a logic 1.

T is a sensor buried in the road inside the tunnel. It produces a logic 1 when an oncoming car is in the tunnel.

The red stop light **R** comes on when a lorry is detected or when there is an oncoming car in the tunnel. **R** will light up when it receives a logic 1.

The green go light **G** comes on when a car is detected and there are no oncoming cars in the tunnel. **G** will light up when it receives a logic 1.

(a) Complete the truth table.
Some of the data has already been entered for you.

Input			Output		
Sensor T	**Sensor C**	**Sensor L**	**Message display M**	**Red stop light R**	**Green go light G**
0	0	0	0	0	1
0	0	1	0	0	1
0	1	0		0	
0	1	1		1	
1	0	0		1	
1	0	1	0	1	0
1	1	0		1	
1	1	1		1	

(4)

(b) Write the simplest Boolean expression for the red stop light **R** in terms of **T**, **C** and **L**.

.....

(2)

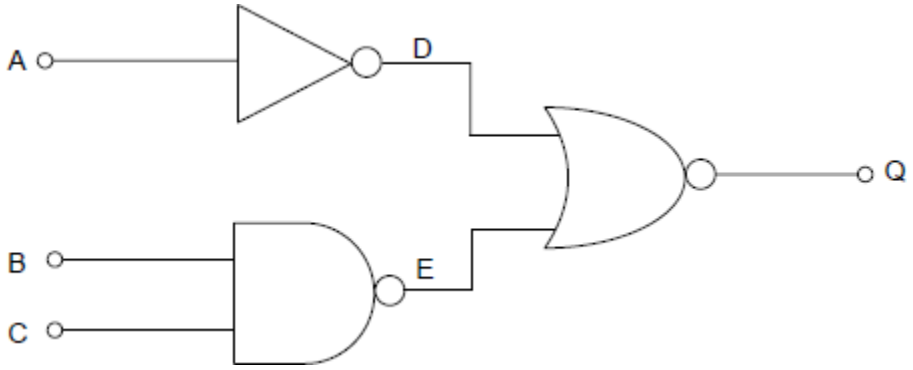
(c) The expression for the green go light **G** could be written as **G** = $\overline{T}.(\overline{C}+\overline{L})$

Draw on **Figure 2** the logic diagram for this expression using only NOT, AND and OR gates.

Figure 2

(3)
(Total 9 marks)

7 As part of his project, a student constructs the following logic circuit.



(a) Write down the Boolean expressions for:

D = ...

(1)

E = ...

(2)

(b) Write down the Boolean expression for Q in terms of D and E.

Q = ...

(2)

(c) Complete the truth table below for the logic circuit above.

A	B	C	D	E	Q
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

(4)

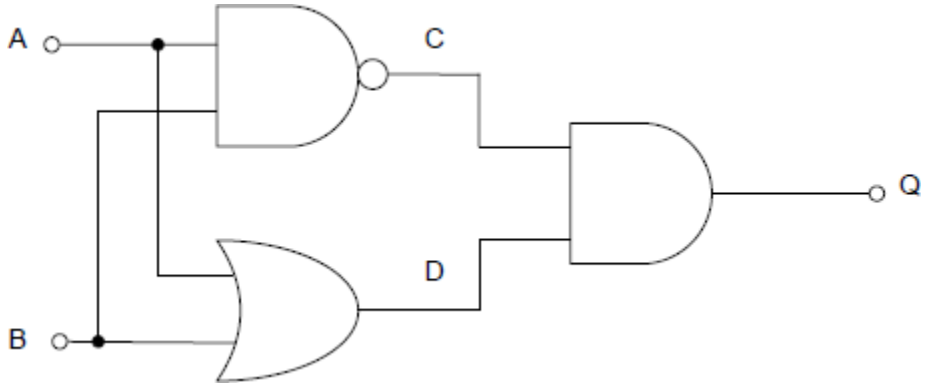
(d) His supervisor suggests that the logic circuit can be simplified. What single logic gate would have the same function as the whole circuit above?

.....

(1)

(Total 10 marks)

8 A student constructs a circuit from the following logic diagram.



(a) Complete the truth table below for this logic diagram.

A	B	C	D	Q
0	0			
0	1			
1	0			
1	1			

(3)

(b) Write down Boolean expressions for the logic signals at C, D and Q in terms of the inputs A and B.

C = ...

(1)

D = ...

(1)

Q = ...

(2)

(c) What single logic gate could perform the function of the whole circuit above?

.....

(1)

(Total 8 marks)

9 A student designs a high power lamp system which flashes when the music reaches a certain sound level at a party. The system will automatically switch on when the volume of music received by a microphone, that gives only a low output voltage, exceeds a set level which can be adjusted. 5 Hz pulses generated in the system are then gated through to a driver which controls a lamp.

(a) Draw a system diagram as a possible plan for this system.

(8)

(b) In which subsystem(s) could

(i) an op-amp be used?

.....

.....

(2)

(ii) a potentiometer be used?

.....

(1)

(iii) a MOSFET be used?

.....

(1)

(Total 12 marks)

10 A student is designing a simple testing device to check that metal bars used in a factory are cut to a set length. The device uses three sensitive switches, A, B, and C, which give a logic 1 when pressed.

The bar is placed in the device and pressed against switch A.

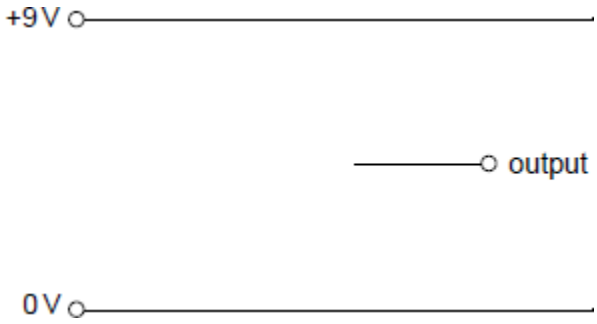
(a) The device operates from a 9 V power supply.

(i) State what is meant by logic 1 in this system.

.....

(1)

(ii) Complete the circuit diagram below, adding a resistor and switch so that the output gives a logic 1 when the switch is pressed.



(2)

(b) If the bar is the correct length when placed against switch A, it presses switch B, but not switch C.

There are three outputs:
L is high if the bar is too long
R is high if the bar length is the right length
S is high if the bar length is too short.

If the bar is not pressed against switch A, all outputs are low.

Write Boolean expressions for the outputs, in terms of A, B, and C.

L = ...

(1)

R = ...

(1)

S = ...

(1)

(c) Draw a logic diagram, using any logic gates, to show how output R can be produced from inputs A, B and C.

(3)

(d) Convert your logic diagram in part (c) to one that uses only NOR gates, drawing the converted system with the smallest number of gates possible in the space below.

(3)
(Total 12 marks)

11 The Boolean equation for a logic circuit with inputs A and B and output Q is:

$$Q = (A \cdot B) + (\overline{A} \cdot \overline{B})$$

(a) Complete the truth table to show the logic values of the terms below for all the combinations of the inputs A and B.

A	B	$\overline{A}$	$\overline{B}$	A.B	$\overline{A} \cdot \overline{B}$	Q
0	0					
0	1					
1	0					
1	1					

(5)

(b) Complete the diagram below to show how a logic circuit can be constructed that has the same function as the Boolean equation above using **two** AND gates, **two** NOT gates, and **one** OR gate.

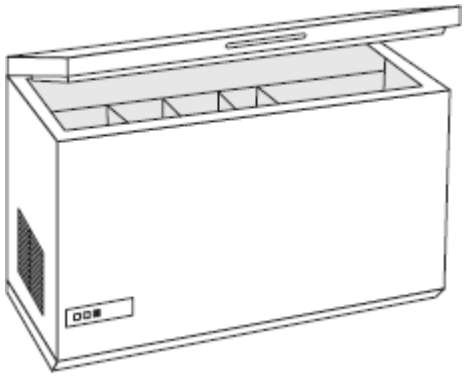
(5)

(c) State the logic function of the complete circuit above.

.....

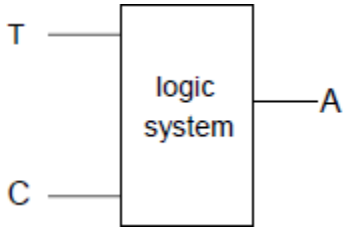
(1)
(Total 11 marks)

12 A butcher wants to fit an alarm to a deep freeze, which will warn him if there is a danger of damage to stock in the freezer.



The freezer has sensors with the following outputs:

T is logic 1 if the temperature is too high to store frozen food; and logic 0 if the temperature is at or below the required temperature
C is logic 1 if the lid is closed and logic 0 if the lid is open.



A student is asked to produce a logic system to give an output A to operate the alarm (the alarm sounds if A is high). He decides that the alarm should sound if:

the lid is closed and the temperature is too high, or
the temperature is low and the lid is left open.

(a) He designs a system to implement this function. Write a Boolean expression for the output A, in terms of T and C.

.....

(3)

(b) Draw a logic diagram for the system, using any type of logic gates.

(5)

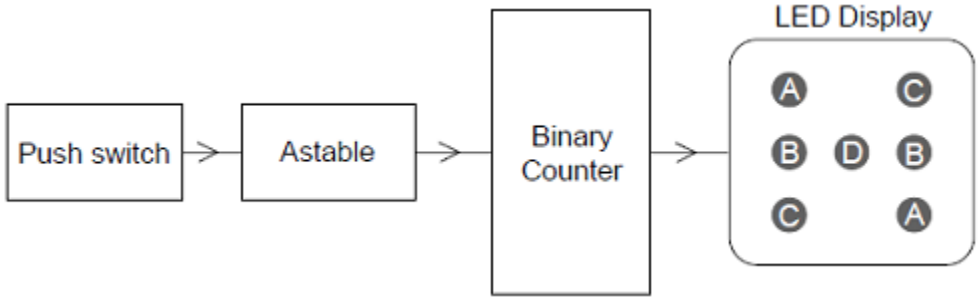
(c) Using NAND gates only, draw a diagram of a logic system which has the same function as a 2-input OR gate.

(2)

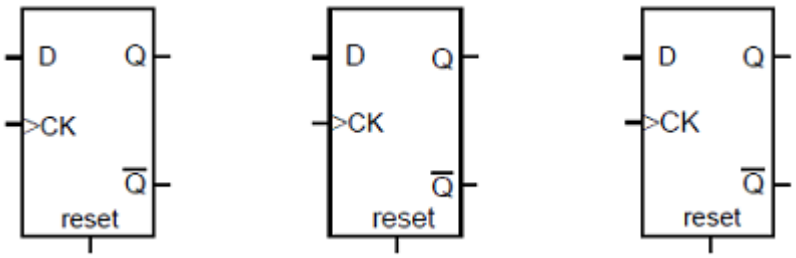
(d) Draw a logic diagram for the system in part (b), using NAND gates only. Draw a ring round any redundant gates or re-draw the final system.

(5)
(Total 15 marks)

13 An electronic dice is to be constructed so that when a push switch is operated, the dice counts very quickly and continuously from 1 to 6. When the push switch is released, the number the dice has counted to, is displayed. The dice will consist of the following subsystems.



The binary counter consists of three rising edge triggered D-type flip-flops. The counter outputs are X, Y and Z. The most significant bit is Z.



(a) (i) On the diagram of the binary counter above, show how these flip-flops must be connected to form a 3-bit binary up-counter. Label the input from the astable and the three outputs X, Y and Z.

(5)

(ii) Only six possible output states are required from the binary counter for the operation of the dice. Add to the diagram of the binary counter the additional connections and components needed to make the counter count from 0 to 5 and then reset on the sixth input pulse.

(3)

(b) The outputs from the binary counter are to be decoded to operate the display to produce the dice numbers. Complete the table below to show how the dice output is related to the binary counter output.

Binary counter output		**Dice output**	
Denary	**Binary Z Y X**	**Dice number**	**LED on**
0	0 0 0	1	D
1	0 0 1	2	A
2	0 1 0	3	D, A
3		4	
4		5	A, C,D
5		6	

(5)
(Total 13 marks)

1

(a) force on an electron in a magnetic field depends on speed **(1)**
electrons at different speeds would be focussed differently so image would be blurred **(1)**
[or electrons at different speeds would have different (de Broglie) wavelengths
therefore resolution would be reduced]

2

(b) increase in pd increases speed **(1)**
increase in speed/momentum/E_k causes reduction of (de Broglie) wavelength **(1)**
reduced (de Broglie) wavelength gives better resolution **(1)**

3

[5]

2

(a)

A	B	$\bar{A}$	$\bar{B}$	A.B	$\bar{A} \cdot \bar{B}$	Q
0	0	1	1	0	1	1
0	1	1	0	0	0	0
1	0	0	1	0	0	0
1	1	0	0	1	0	1

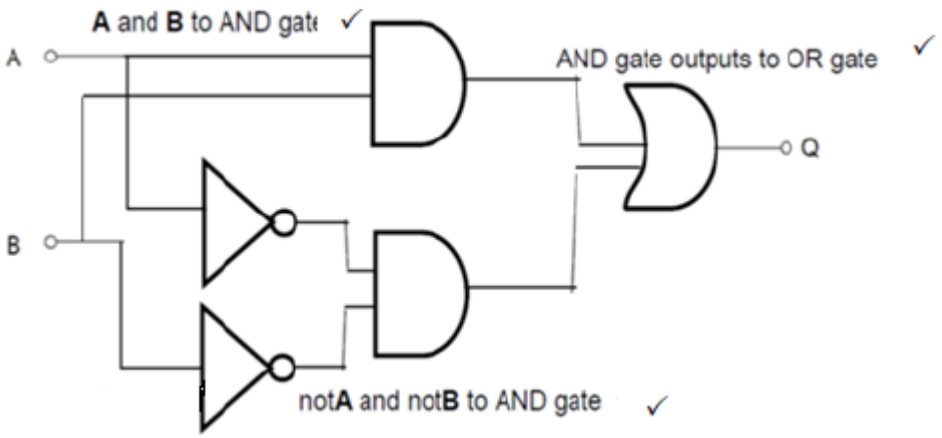
Both correct

First line Q = 1

Third line Q = 0

1

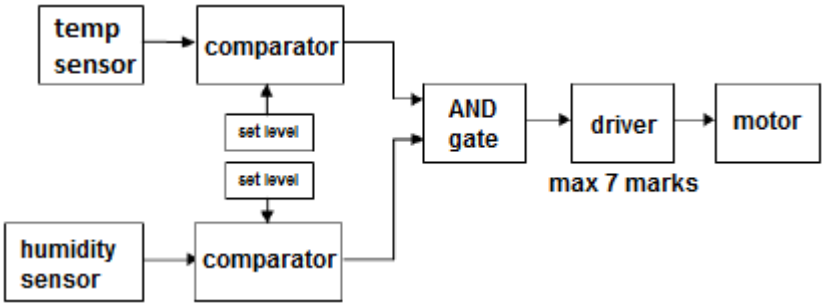
(b)



3

[4]

3 (a)



max 7 marks

7

(b) (i) driver✓

1

(ii) comparator✓

1

(iii) temperature sensor✓

1

(c) (i) 25 + 450 = 475mA✓

1

(ii) 12V × 475mA✓
= 5.7W✓

2

[13]

4 (a) D = C + B

1

E = $\overline{A}$

1

G = $\overline{A+B}$

1

3

(b)

INPUTS			INTERMEDIATE OUTPUTS		
C	**B**	**A**	**D**	**E**	**G**
0	0	0	**0**	**1**	**1**
0	0	1	**0**	**0**	**0**
0	1	0	**1**	**1**	**0**
0	1	1	**1**	**0**	**0**
1	0	0	**1**	**1**	**1**
1	0	1	**1**	**0**	**0**
1	1	0	**1**	**1**	**0**
1	1	1	**1**	**0**	**0**

2 marks for each of correct columns D & G

1 mark for column E

5

(Total 8 marks)

5

(a)

A	B	a	b	c	d	e	f	g	Display
0	0	**0**	**0**	**0**	**1**	**1**	**1**	**0**	L
0	1	**1**	**0**	**1**	**1**	**0**	**1**	**1**	S
1	0	**1**	**0**	**1**	**1**	**0**	**1**	**1**	S
1	1	**0**	**1**	**1**	**0**	**1**	**1**	**1**	H

1 mark for row L

1 mark for row S (both)

1 mark for row H

3

(b) EXOR gate

1

(c) (i) Different combinations produce different brightness

1 Disadvantage

1

(ii) R=V/I; (5V − 2.2V) / 20mA; 2.8V / 20mA = 140Ω

1 mark for 2.8V drop

1 mark for answer

2

(iii) E24 = 150Ω

1 mark for answer

1

(8)

6 (a)

INPUTS			OUTPUTS		
Tunnel Sensor T	**Car Sensor C**	**Lorry Sensor L**	**Message Display M**	**Red Stop light R**	**Green Go light G**
0	0	0	**0**	0	**1**
0	0	1	**0**	0	**1**
0	1	0	**0**	0	**1**
0	1	1	**1**	1	**0**
1	0	0	**0**	1	**0**
1	0	1	**0**	1	**0**
1	1	0	**0**	1	**0**
1	1	1	**1**	1	**0**

Column M − 2 marks
Column G − 2 marks

4

(b) **R = T + (C.L)**

1 mark for terms

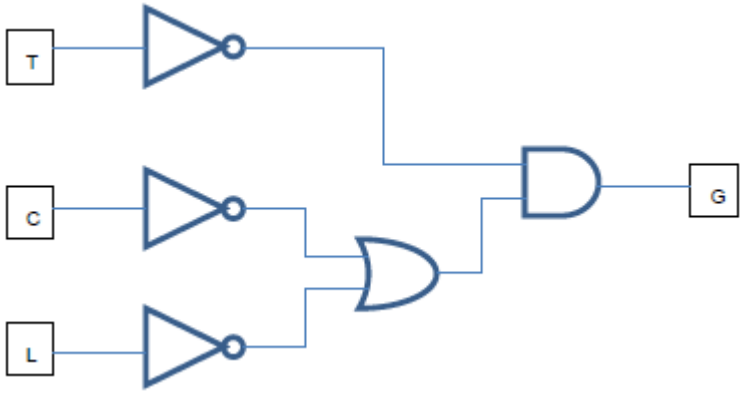
1 mark for OR

Or for full expression **S = T +(**$\overline{T}$**.C.L)**

Max 1 mark

2

(c)



3

(Total 9 marks)

7 (a) $\overline{A}$✓

$\overline{B.C}$✓✓

3

(b) $\overline{D + E}$✓✓

2

(c)

A	B	C	D	E	Q
0	0	0	**1**	**1**	**0**
0	0	1	**1**	**1**	**0**
0	1	0	**1**	**1**	**0**
0	1	1	**1**	**0**	**0**
1	0	0	**0**	**1**	**0**
1	0	1	**0**	**1**	**0**
1	1	0	**0**	**1**	**0**
1	1	1	**0**	**0**	**1**
			✓	✓	✓✓

4

(d) (3-input) AND gate✓

1

[10]

8 (a)

A	B	C	D	Q
0	0	1	0	0
0	1	1	1	1
1	0	1	1	1
1	1	0	1	0
		✓	✓	✓

3

(b) C = $\overline{A.B}$✓
D = A+B✓
Q = $\overline{A.B}$. ✓ (A + B) ✓

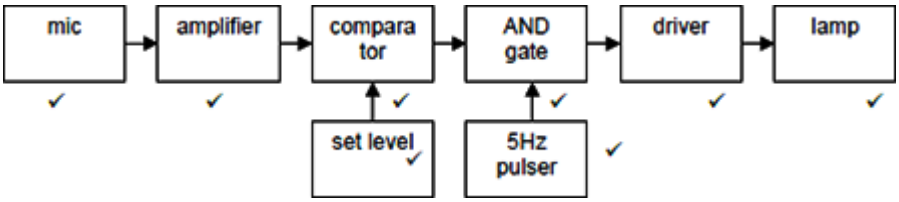
4

(c) EXOR✓

1

[8]

9 (a)



8

(b) (i) amplifier ✓ comparator ✓

2

(ii) set level✓

1

(iii) driver✓

1

[12]

10 (a) (i) 9V / >4.5V / high voltage✓

1

(ii) resistor in series with switch from 0V✓
switch between 9V and output✓

2

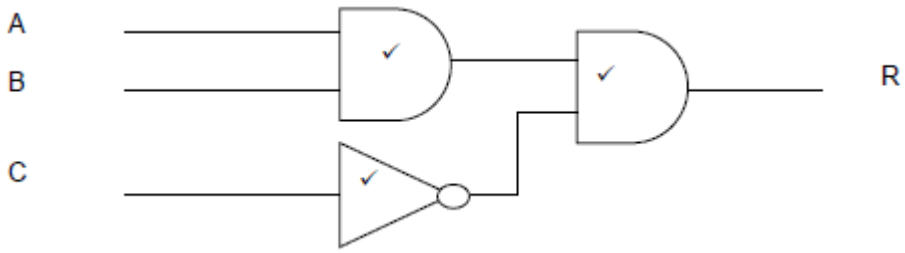
(b) L = A.B.C (or A.C) ✓

R = A.B.$\overline{C}$✓

S = A .$\overline{B}$.$\overline{C}$✓ (or A.$\overline{B}$) (allow)

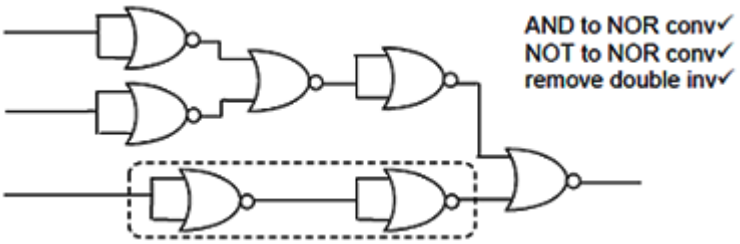
3

(c)



3

(d)



3

[12]

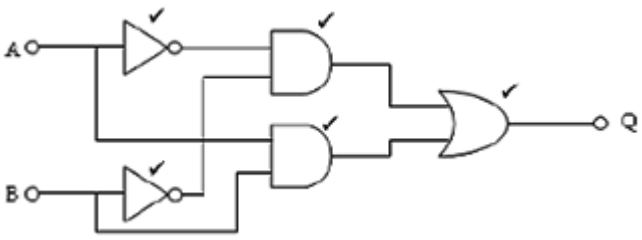
11 (a)

A	B	$\overline{A}$	$\overline{B}$	A . B	$\overline{A}$.$\overline{B}$	Q
0	0	**1**	**1**	**0**	**1**	**1**
0	1	**1**	**0**	**0**	**0**	**0**
1	0	**0**	**1**	**0**	**0**	**0**
1	1	**0**	**0**	**1**	**0**	**1**

✓ ✓ ✓ ✓ ✓

5

(b)



5

(c) EXNOR ✓

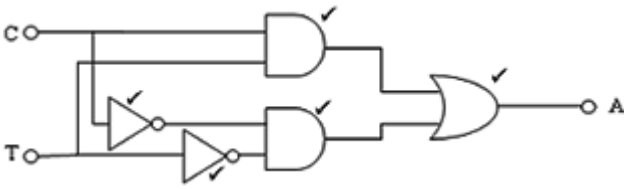
1

[11]

12 (a) A = C.T✓ +✓ $\overline{C}.\overline{T}$✓

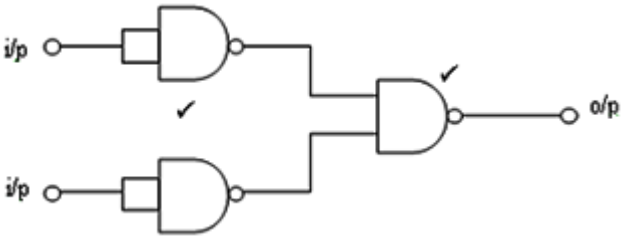
3

(b)



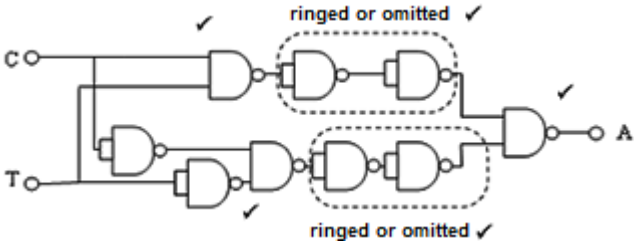
5

(c)



2

(d)



5

[15]

13 (a) (i) D to inv. output, ✓
CK to inv. output, ✓
Resets together ✓
label astable input ✓
three labelled outputs ✓

5

(ii) AND gate, ✓
output to Reset, ✓
inputs from Y and Z ✓

3

(b)

Binary counter output		Dice output	
Denary	Binary Z Y X	Dice number	Lamps on
0	0 0 0	1	D
1	0 0 1	2	A
2	0 1 0	3	D, A
3	0 1 1	4	A, C
4	1 0 0	5	A, C, D
5	1 0 1	6	A, B, C

one per correct answer ✓ ✓ ✓ ✓ ✓

5

[13]